Lat 40.72528 Lon -121.04952

Forest Health Protection

Pacific Southwest Region
Northeastern California Shared Service Area

Date: August 1, 2018
File Code: 3420

To: District Ranger, Eagle Lake Ranger District, Lassen National Forest

Subject: Stand conditions and white fir mortality within the proposed Harvey Project (FHP Report NE18-07)

Background

At the request of Lindsay Grayson and Rachel Rundquist, Foresters, Eagle Lake Ranger District, Danny Cluck, Forest Health Protection (FHP) Entomologist, conducted a field evaluation of the Harvey project area on June 14, 2018. The objective of this visit was to evaluate existing stand conditions, including recent white fir mortality. Treatment alternatives were discussed in the field and are documented in this report. Recommendations provided in this report will assist in the formulation of silvicultural prescriptions aimed at reducing overall stand density with an emphasis on greatly reducing the relative abundance of white fir.

Figure 1. Legacy pine with white fir understory.

Key Findings

- White fir abundance has increased within the proposed project area due in large part to fire exclusion and is now the dominant conifer species in many stands that were historically dominated by fire-adapted ponderosa and Jeffrey pine (Figure 1).

Danny Cluck
Forest Entomologist
530-252-6431
dcluck@fs.fed.us

Bill Woodruff
Plant Pathologist
530-252-6880
wwoodruff@fs.fed.us

- Fir engraver beetle-caused white fir mortality has increased dramatically over the past three years (Figure 2). White fir mortality was greatest in denser stands but was found in nearly every area of the project regardless of stand density.

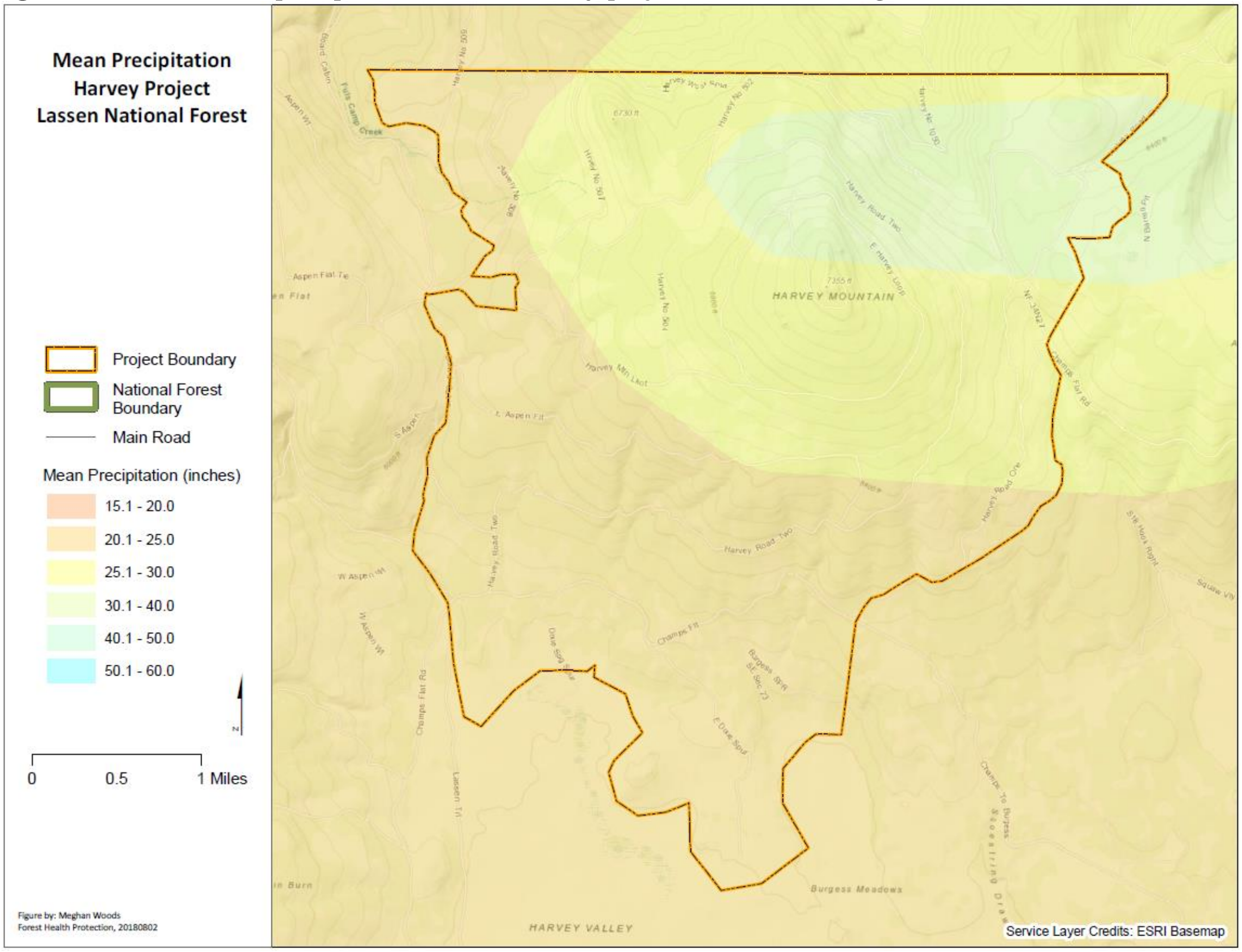
Figure 2. Dead and dying white fir on Harvey Mountain in 2016 (Photo credit: R5 ADS).

- This recent white fir mortality event followed a similar drought related mortality event from 1987-1992, showing that unsustainable stand conditions continue to exist in the Harvey project area.
- Fuel loading from dead and down white fir over the past 30 years has put most areas at extreme risk to stand replacing wildfire.
- Ponderosa and Jeffrey pine stands at lower elevations are generally overstocked and susceptible to bark beetle-caused mortality during drought.
- Green tree thinning, salvage and sanitation are highly recommended throughout the project area to reduce stand density, greatly reduce the abundance of white fir, reduce fuels and begin to restore what was once a fire-adapted pine dominated ecosystem.
- All stands, with few exceptions, need to be managed for the pine component. Without a major effort to reduce the abundance of white fir, periodic outbreaks of fir engraver beetle in response to drought will continue to contribute to excessive fuel loading and ultimately result in stand replacing wildfire.

Description of the project area

The Harvey project is located approximately 30 miles northwest of Susanville, CA at elevations ranging between 5,600 and 7,340 feet (40.725279° N and 121.049522° W). Annual precipitation ranges between 20 and 35 inches (Figure 3). Forest cover is a combination of native stands and pine plantations. The native stands consist primarily of white fir (*Abies concolor*) at upper elevations with lesser amounts of ponderosa pine (*Pinus ponderosa*) and Jeffrey pine (*Pinus jeffreyi*). Lower elevations and south facing slopes are primarily ponderosa and Jeffrey pine with white fir, incense cedar (*Calocedrus decurrens*) and western juniper (*Juniperus occidentalis*). Most forested areas are densely stocked, have experienced elevated levels of tree mortality associated with insects, pathogens and drought and contain high numbers of standing and down dead trees.

Figure 3. Mean annual precipitation for the Harvey project and surrounding area.



Management objectives

The Harvey project proposes to reduce fuels and improve forest health through thinning and prescribed burning. Stocking targets for eastside pine stands will reduce susceptibility to bark beetles and will be generally lower than higher elevation white fir and mixed conifer stands.

Residual stands will be more open, increasing the amount of available soil moisture and sunlight for individual trees. White fir abundance will be substantially reduced throughout the project area.

Forest insect and disease conditions

Bark beetle activity observed during the site visit was primarily on white fir where fir engraver beetle (*Scolytus ventralis*) has recently caused extremely high levels of tree mortality throughout the project area. White fir mortality was also associated with Heterobasidion root disease (caused by *Heterobasidion occidentale*, formerly referred to as S-type annosus root disease) and white fir dwarf mistletoe (*Arceuthobium abietinum* f. sp. *concoloris*) in some locations.

Figure 4. Jeffrey pine beetle infested Jeffrey pine, Harvey project, 2017.

A few Jeffrey pine growing within dense stands were recently attacked and killed by Jeffrey pine beetle (*Dendroctonus jeffreyi*) (Figure 4).

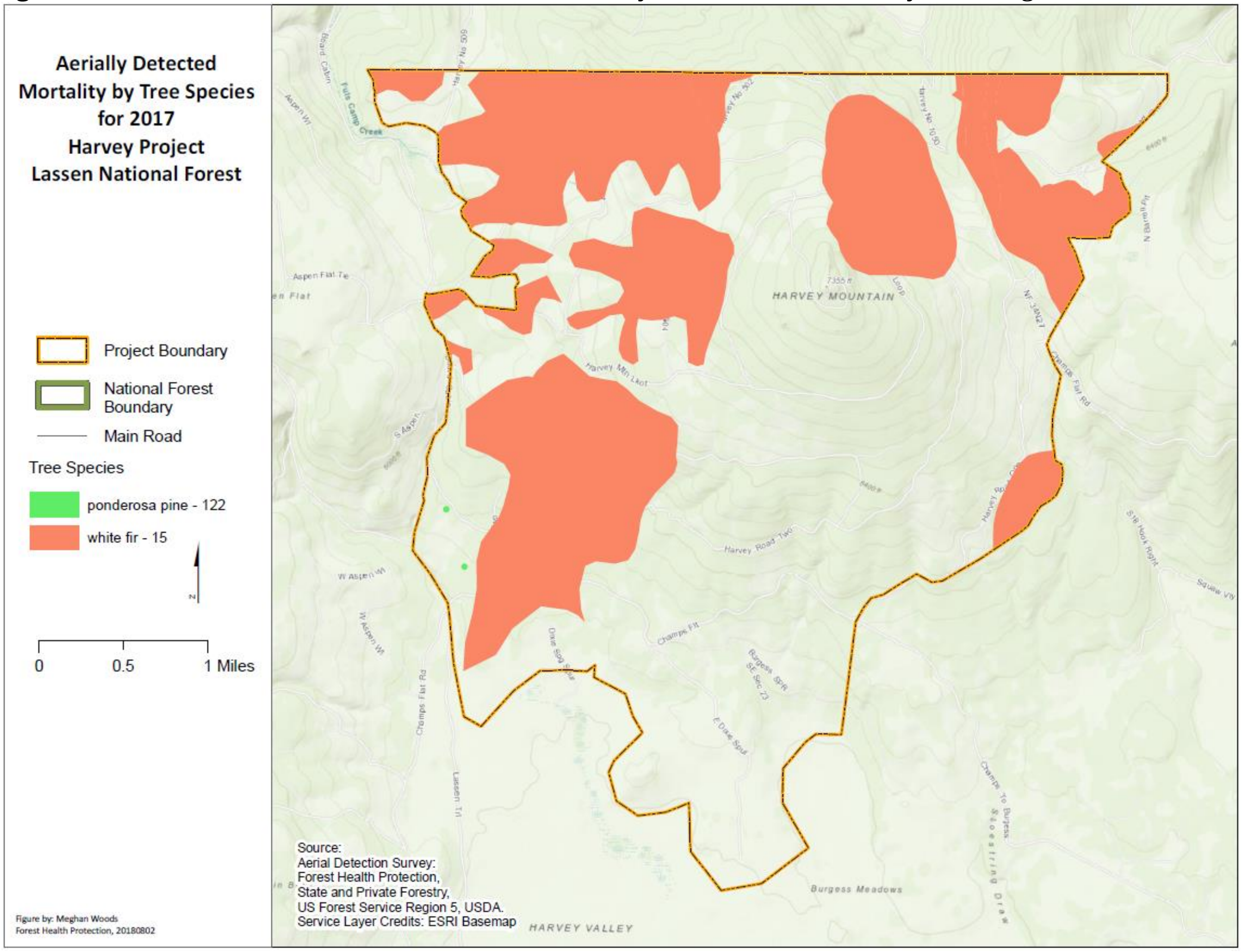
Forest Health Protection monitoring of stand conditions in thinned and unthinned areas within the proposed Harvey project area since 2000 has also documented high levels of tree mortality in unthinned stands including fir engraver beetle-caused mortality of white fir and western pine beetle (*Dendroctonus brevicomis*) caused mortality of ponderosa pine (Figure 5)

Figure 5. Tree mortality observed in Harvey Mountain monitoring plots

TREE MORTALITY 2000-2015 Thinned stand (BA = ~80 sq.ft./acre) vs. Unthinned stand (BA = ~150 sq.ft./acre)		
THINNED (dead trees/acre)		
	0-6" DBH	6+" DBH
PP/JP	3	2
WF	1	0
UNTHINNED (dead trees/acre)		
	0-6" DBH	6+" DBH
PP/JP	24	6
WF	286	44

Aerial detection surveys (ADS) in 2017 also mapped high levels of white fir mortality caused by fir engraver beetle throughout the project area (Figure 6).

Figure 6. Extent of white fir and other conifer mortality in 2017 as detected by ADS flight.



Stand conditions and mortality related to recent and future climate trends

Many of the forested areas in Harvey project area are overstocked and have exhibited elevated levels of tree mortality caused by bark beetles, especially during periods of drought (Figures 7 and 8, Table 1). This mortality combined with high stand density has resulted in heavy fuel loading in many areas and a corresponding increase in potential fire behavior (Figure 9).

Most stands have also experienced a species composition shift from shade intolerant ponderosa and Jeffrey pine to more shade tolerant white fir in the absence of fire. White fir is now abundant on many sites that are considered high to extreme risk for mortality during drought periods (based on average annual precipitation, see pages 7 and 8). The mortality resulting from the recent drought as well as previous droughts provides ample proof that these areas do not support healthy stands of white fir over the long-term. In the Harvey project area, fir engraver beetle-caused tree mortality has generally increased since 2012, accelerating to outbreak levels from 2015 through 2017 (Table 1).

Figure 7. Number of dead trees per acre mapped by ADS from 2008 to 2017.

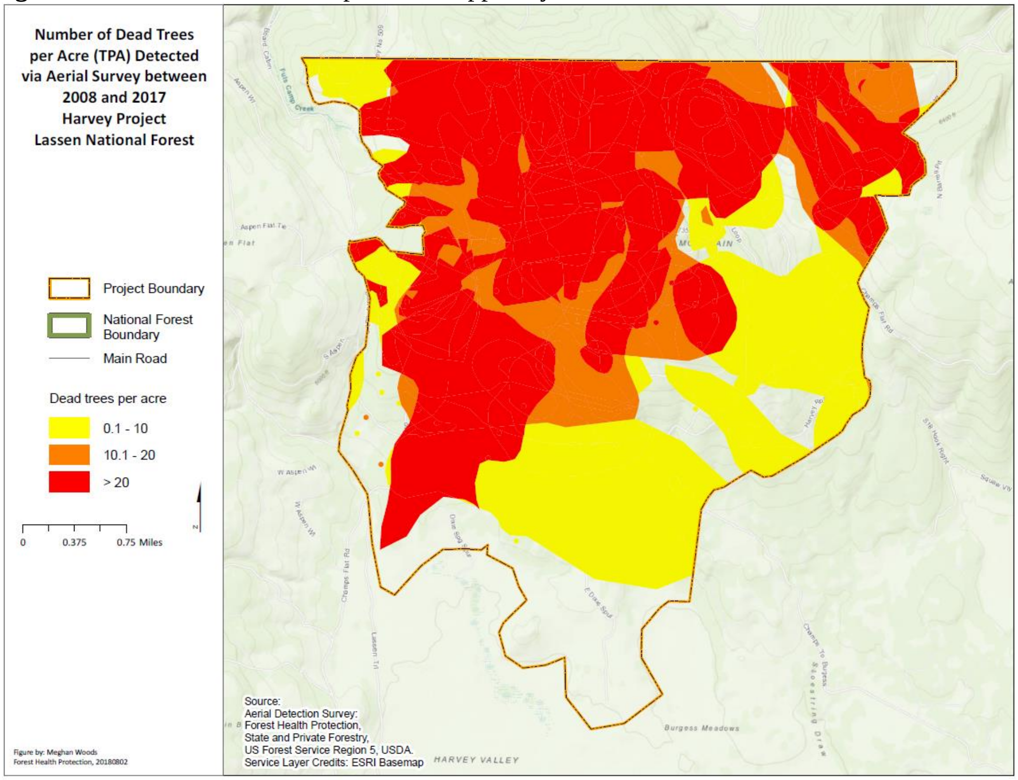


Figure 8. Number of years with elevated tree mortality mapped by ADS between 2008 and 2017.

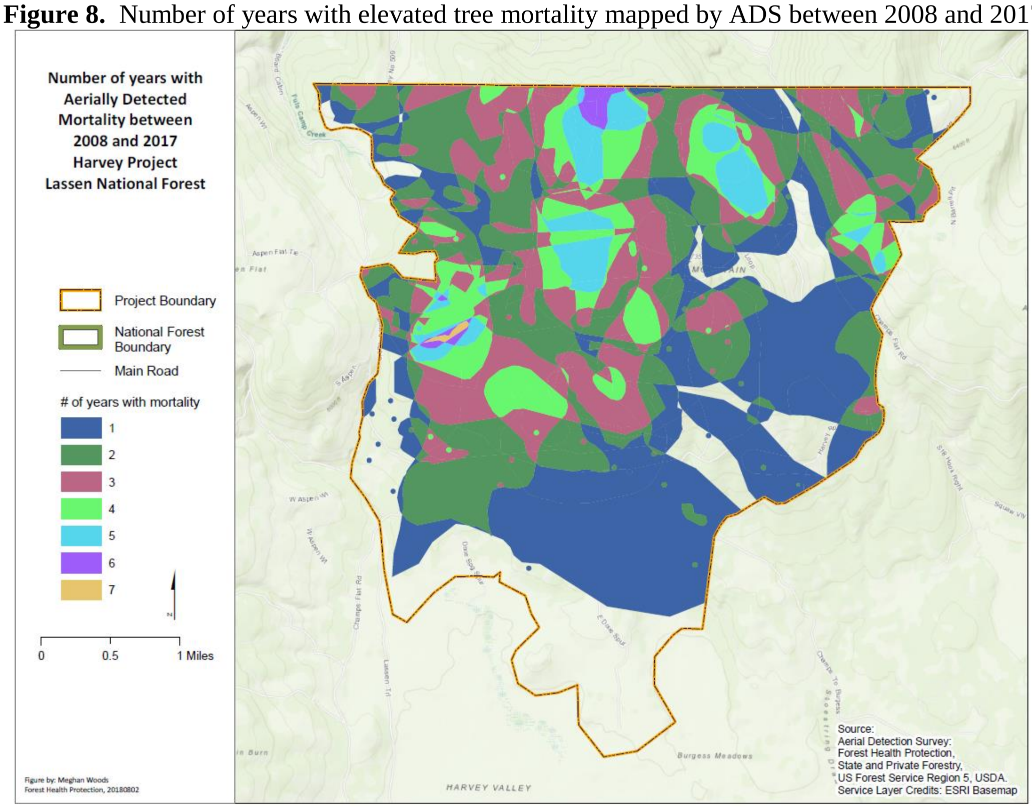


Table 1. Acres with mortality, estimated dead trees per acre and estimated total # of dead trees from R5 Aerial Detection Surveys and Palmer Hydrologic Drought Index (PHDI) (average of CA Divisions 2 and 3[1]) by water year (Oct-Sept) within the Harvey project area.

Year	Acres	Dead Trees/Acre	Total # of Dead Trees	PHDI[2]
2017	3,010	20.9	62,974	3.00
2016	5,644	10.1	57,047	-1.32
2015	3,939	15.6	61,316	-3.34
2014	962	2.8	2,715	-3.56
2013	1,426	1.9	2,769	-2.16
2012	198	2.6	513	-0.59
2011	410	1.1	465	2.78
2010	327	2.1	695	-0.14
2009	752	1.0	772	-2.98
2008	<1	<1	1	-3.16

[1] California Divisions 2 and 3 encompass most of northeastern California.

[2] PHDI values ranging from -2.00 to -2.99 are considered moderate drought conditions. Severe drought conditions range from -3.00 to -3.99 and extreme drought conditions are below -4.00.

Figure 9. Dead and down white fir from previous drought and fir engraver beetle activity.

White fir that succumb to fir engraver beetle attacks are typically predisposed by other factors that compromise their health and vigor. In the Harvey project area, high stand density, prolonged drought, trees growing off site, dwarf mistletoe and Heterobasidion root disease are all contributing factors in declining tree health and mortality.

The distribution of both white fir and white fir mortality are strongly influenced by the mean annual precipitation. The lower limit of precipitation in the natural range of white fir is about 20 inches (Fowels, H.A. 1965). The isohyetal map of mean annual precipitation provided in this report (Figure 2) can be used to rate the risk of white fir mortality (Schultz 1994).

<u>Low risk: 40+ inches annual precipitation **(~0% of Harvey Project)**.</u> These areas easily support stands of white fir. Mortality will be low, even during drought periods. Thinning will increase the rate of tree growth, but will show only slight differences in tree mortality.

<u>Medium Risk: 30-40 inches of annual precipitation **(~20% of Harvey Project)**.</u> Stands in these areas often have a high percentage of white fir that may achieve a considerable age and size. Prolonged drought may cause mortality of 5-10% of the stems. Periodic thinning which

concentrates on removing white fir ingrowth will lower mortality by maintaining a more sustainable amount of biomass, as well as promoting a more stable mixed species stand.

High Risk: 25-30 inches of annual precipitation **(~30% of Harvey Project**). In the absence of fire, these areas have stands which are dominated by densely stocked, small diameter white fir. The species distribution by age class shows an increase in the relative percentage of white fir in these stands following fire suppression. Prolonged drought may cause mortality in excess of 50% of the stems. The risk of mortality can be lowered by thinning to a wide spacing prior to the onset of drought, and by promoting a mix of species that are native to the site. *Note: this zone within the Harvey project includes some larger diameter white fir (>12" dbh) that have also established following fire suppression. These trees should be targeted for removal as well as the smaller diameter white fir stems in order to establish and maintain a pine, fire-adapted system.*

Extreme risk: 20-25 inches of annual precipitation **(~50% of Harvey Project**). In some cases the shade tolerant trees may live long enough to achieve an intermediate or co-dominant crown position. Prolonged drought may cause mortality of 80-85% of the stems. In stands where the total stocking of both overstory and understory is high, mortality may also occur in the pines. The risk of mortality may be lowered by managing groups of pine at wide spacing.

Nearly all of the project area receives less than 30 inches of annual precipitation and no area receives more than 40 inches of annual precipitation. Thirty inches is below what is generally required for healthy white fir forests to exist over the long-term. Therefore, even at the lowest stocking levels, white fir growing on these sites are at a high to extreme risk for fir engraver beetle-caused mortality during periods of drought. Even in stands that receive between 30 and 40 inches, the risk of mortality during drought is still considered medium.

A white fir levels of growing stock study conducted by Cochran (1998) on the Deschutes and Fremont National Forests between 1983 and 1995 provides some additional information to consider when managing white fir in lower precipitation areas. Plots were thinned in 1982 and again in 1985 to a residual stand density index (SDI) of 112, 168, 224 or 280. These corresponded to growing stock levels of 20, 30, 40 or 50 percent of normal density. Elevations for his study plots ranged from 4,500 to 5,900 feet with average annual precipitation ranging from 16 to 31 inches. A general drought prevailed over the study areas from the late 1970's to the mid 1990's and mortality between 1991 and 1995 destroyed the study. Mortality on Blocks 2, 3 and 4 of the study was attributed to fir engraver beetles. Mortality from fir engraver beetles appeared to increase with increasing stand densities and was above acceptable levels even at the lowest stand density (20 percent of density considered normal for white fir).

From Cochran 1998:

"Healthy stands of white fir grow very rapidly, produce a dense crown cover, and are visually pleasing. These results, however, raise doubts about growing white fir stands on sites with mean annual precipitation rates below 32 inches even if stand densities are kept very low. The four widely scattered stands represented in this study apparently grew well for more than 60 years and reached commercial size before severe mortality occurred. Where significant amounts of white fir are present, managers need the ability to manipulate stand composition to minimize mortality.

Future stands on similar sites should have a large component of ponderosa pine and should be managed by using ponderosa pine stocking guides (Cochran and others 1994). These density levels would allow the individual fir trees, intermingled with pine, to reach commercial size at fairly young ages. If drought, disease outbreaks, or severe insect infestations occur, the white fir could be removed, leaving ponderosa pine on the site. Ponderosa pine quickly responds to new growing space even at old ages and would quickly take advantage of the available site resources. Ferrell (1978) reports that trees under high moisture stress (-20 bars dawn xylem pressure or higher negative pressures) for protracted summer periods are more susceptible to successful fir engraver attacks than are trees under less stress. If prolonged droughts are forecast, removal of most of the white fir on drier sites may be advisable. This would prevent the buildup of fir engraver populations that could migrate to moist sites and inflict heavy damage where, historically, white fir has survived dry periods."

In a Warner Mountain study by Egan et al (2010), the density of fir engraver beetle-caused tree mortality was greater in unthinned versus thinned mixed conifer stands but the percentage of mortality relative to available host trees was similar. This further suggests that white fir growing in high risk sites (based on average annual precipitation) are susceptible to drought and fir engraver-beetle caused mortality regardless of stocking levels.

From Egan et al (2010):

"Our findings varied in mixed conifer areas as the density of, but not percent, FEN (fir engraver beetle)-caused mortality was reduced in thinned areas. These results do not support the use of thinning to reduce percent mortality or the relative number of residual white fir trees susceptible to FEN-caused mortality during times of drought. Conversely, this study does support the efficacy of thinning to reduce the density of mortality or absolute number of beetle-killed trees in mixed conifer stands exposed to drought conditions. The density of residual white fir host and elevation (likely a proxy for water availability) were important factors associated with white fir mortality in our study. These findings indicate thinning effectiveness in reducing fir mortality was directly proportional to the amount of post-treatment density white fir retained. Thus, our findings support discriminating against residual fir and retaining a greater pine component, similar to historic compositions (Vale, 1977), during thinning treatments to reduce the density of FEN-caused mortality even during periods of drought."

Several Forest Health Protection reports since 1994 have also identified unhealthy white fir stand conditions on northeastern California forests and the need for thinning (FHP reports available upon request). Most of these reports concurred that without treatment, the trend for most stands of increasing stand density, high levels of insect and disease activity and elevated levels of tree mortality would likely continue until a major disturbance event such as a stand replacing fire occurred. Schultz (1994) recommended thinning white fir stands on the Big Valley RD, Modoc NF, to manage for pine as a more sustainable stand structure; stating, "Unless these areas are being managed for habitat for a species which is dependent on small diameter dead white fir, or there is an economic market for small diameter white fir, then it would promote a more sustainable stand structure to manage for pine."

Predicted climate change is likely to impact trees growing in the Harvey project area over the next 100 years. Although no Lassen National Forest specific climate change models are available at this time, there is a general consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (K. Merriam and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Sierra Cascade Province, including the Plumas, Modoc, and Lassen National Forests).* The risk of bark beetle-caused tree mortality will likely increase for all conifer species under this scenario, especially drought intolerant white fir. Improving the resilience of stands to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape.

<u>Considerations for thinning treatments</u>

Most white fir and mixed conifer stands on Harvey Mountain should be managed for the pine component as much as possible. This includes all white fir dominated stands with a ponderosa/Jeffrey pine component. This will likely require a change from the current mixed conifer or white fir stand typing in many areas to yellow or eastside pine, better representing historic species compositions and desired future conditions. Having the ability to significantly reduce stand density and the abundance of white fir is critical to successful ecological restoration within the project area.

Thinning stands without significantly reducing stocking levels and the abundance of white fir will not likely result in a change in trajectory towards a pine dominated fire-adapted condition. A high residual component of white fir will continue to produce abundant seed, increasing the number of white fir seedlings relative to pine seedlings. Subsequent and frequent prescribed fire can help change the trajectory of seedling establishment towards pine but its use is often hampered by lack of appropriate burning conditions, air quality concerns or adequate resources for implementation. Even if prescribed burning is accomplished, is not likely to significantly reduce the number of larger diameter, seed producing white fir in thinned stands due to generally thicker bark and higher crown base heights.

When planning thinning treatments, it should be recognized that the target stand density and species composition is an average to be applied across the landscape and some variability may be desired to increase heterogeneity. Individual high-value trees, such as mature pines, and drier areas dominated by ponderosa/Jeffrey pine should benefit by having the stocking reduced to lower levels. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as forked and/or broken-topped trees. Higher concentrations of white fir can be retained at higher elevations that receive >30" of average annual precipitation or on north facing slopes that receive 25 to 30" of average annual precipitation. Tree removal should include trees heavily infected with dwarf mistletoe, root disease and trees infested with bark beetles. Small group harvest could also be utilized to remove white fir that are within known Heterobasidion root disease centers or are heavily infested with dwarf mistletoe. This would create openings that could be planted with ponderosa and Jeffrey pine. These types of prescriptions would be consistent with 2014 Farm Bill Section 602(d)(1) direction that allows the

implementation of projects "….to reduce the risk or extent of, or increase the resilience to, insect or disease infestation in the areas."

In most cases, thinning to a relative density of 25 - 40% (relative to the maximum Stand Density Index, or SDI) for a specific conifer species or for a weighted composition of conifer species will effectively reduce competition for limited water and nutrients and reduce the susceptibility to future bark beetle-caused tree mortality. This approach will also increase the longevity of treatments as they should stay below 60% relative density, the general threshold for self-thinning, for many years. For the Harvey project area, the District should consider basing relative density targets on the pine component of most mixed conifer and white fir stands. A possible target could be a maximum stand density index of 450 for ponderosa pine as suggested by Long and Shaw 2005. In areas where white fir will remain the dominant stand component, due to more favorable site conditions for the species, a maximum stand density index of 550 as described by Long and Shaw (2012) may be appropriate.

The latest peer-reviewed research on Jeffrey pine stocking as it relates to Jeffrey pine beetle-caused mortality (Egan et al 2016) and a FHP report for the same study (Egan et al 2009) suggest stocking levels that are at or below SDI 210 (corresponded to < 125 sq.ft./acre of basal area in study plots) to reduce tree mortality during droughts and high bark beetle population pressure. Stocking levels of SDI 110 (corresponded to <80 sq.ft./acre of basal area in study plots) had no Jeffrey pine beetle-caused mortality during the Jeffrey pine beetle outbreak monitored during the study. These stocking guidelines are also appropriate for ponderosa pine (Oliver 1995).

Many stands contain large diameter ponderosa, Jeffrey and sugar pine. Thinning treatments that improve growing conditions for these more shade intolerant species, such as removing a large percentage of the white fir basal area around these trees, would increase their health and vigor, create opportunities for their successful regeneration and improve overall resiliency to disturbance agents (insects, disease, drought and fire). Removing competing trees from the base of large diameter pines combined with stand level thinning has resulted in a measured increase in annual increment growth in old growth ponderosa and Jeffrey pine on the Lassen National Forest (Hood et al 2017).

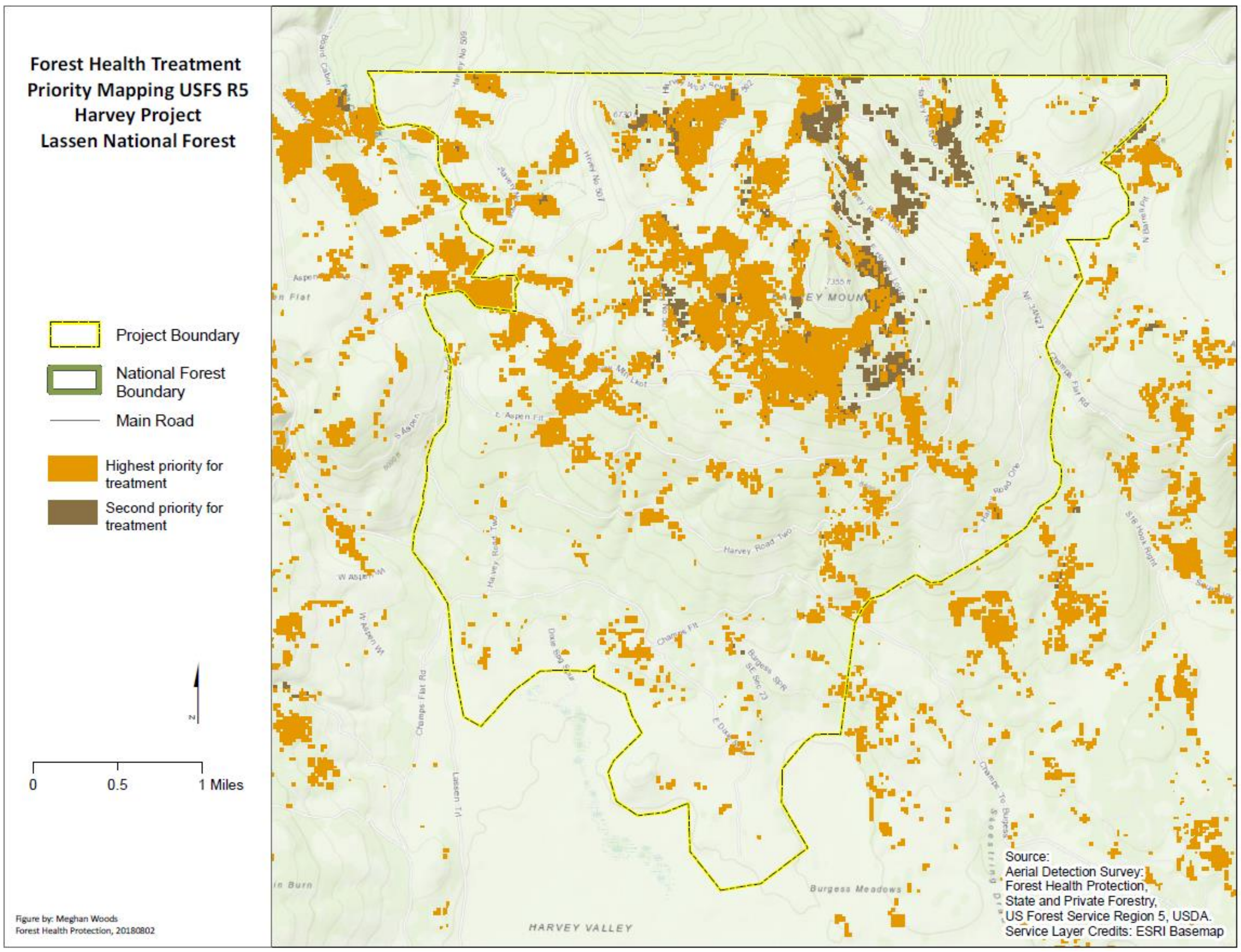
It is recommended that a registered borate compound be applied to all freshly cut conifer stumps >14" in diameter to reduce the chance of creating new infection centers of *Heterobasidion irregulare* and *H. occidentale* formerly referred to as P-type and S-type annosus root disease, through harvest activity. An exception to this recommendation would be treating white fir stumps in yellow pine/white fir stands or more pure white fir stands if there is already a high level of Heterobasidion root disease present as treating white fir stumps in heavily infected stands is ineffective.

Forest Health Protection recently developed a treatment priority map for Region 5 to help land managers prioritize thinning treatments at the landscape level. This map depicts forested areas on National Forest System lands that are the most susceptible to drought and bark beetle-caused tree mortality based on forest type and stand density. These areas also meet the criteria of existing on slopes <=35% and being outside of wilderness areas, wild and scenic river corridors, designated roadless areas and California spotted owl protected activity centers. Additional criteria include not

having burned at moderate to high severity since 1998 and not having been thinned since 2005. In addition to being overly dense, these areas have a history of tree mortality during drought resulting in heavy fuel loads and higher risk of stand replacing wildfire. Highest priority areas consist of high density pine stands, pine-dominated mixed conifer stands and fir-dominated mixed conifer and white fir stands growing on historically pine dominated sites. Second priority areas consist of high density fir-dominated mixed conifer and white fir stand on wetter sites. All mapped stands are California Wildlife Habitat Relationship size class 4, 5 and 6.

Figure 10 shows treatment priority areas within the Harvey project boundary. This mapping effort utilized remotely sensed data to create treatment priority layers for large scale planning and may not be accurate at the stand level. The forest should still use stand records and stand exam data to

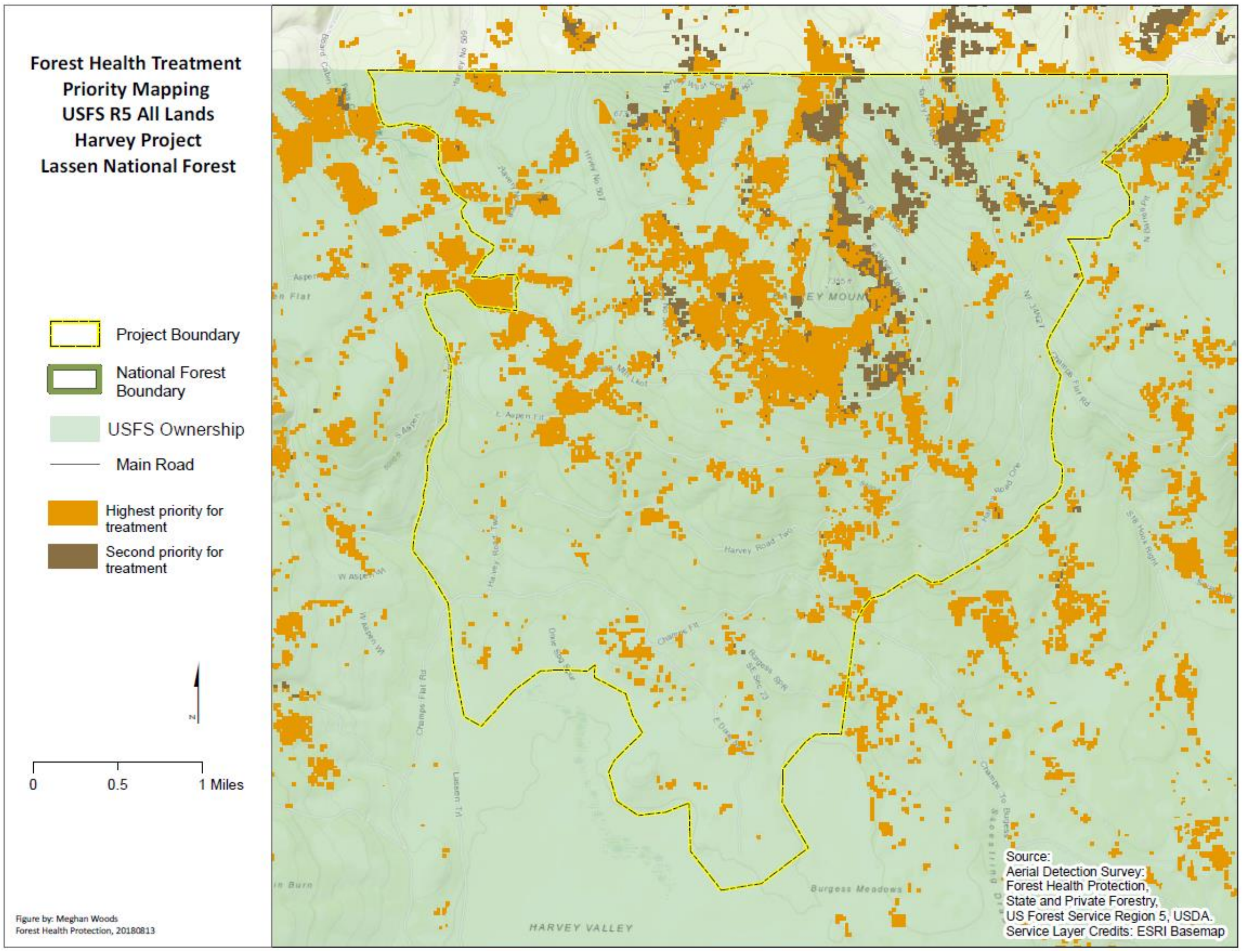
Figure 10. Treatment Priority Areas* at risk to bark beetle-caused mortality within and adjacent to the Harvey project area



*Highest priority treatment areas include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Wilderness areas, inventoried roadless areas, wild and scenic areas, spotted owl protected activity centers, moderate to high severity burned areas since 1998, areas thinned since 2005, areas with >35% slope and all non-National Forest System lands were excluded from this analysis.

identify treatment areas and develop silvicultural prescriptions. An ALL LANDS version of the map was also created that includes wilderness areas, wild and scenic river corridors, designated roadless areas and California spotted owl protected activity centers to evaluate stand conditions in these protected areas. It also includes slopes >35% and all land ownerships (Figure 11).

Figure 11. Treatment Priority Areas (ALL LANDS version)* at risk to bark beetle-caused mortality within and adjacent to the Harvey project area.



*Highest priority treatment areas for ALL LANDS version include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Moderate to high severity burned areas since 1998, areas thinned or that experienced stand replacing disturbance such as clear cuts or bark beetle-caused tree mortality since 2005 were excluded from this analysis.

Considerations for Rx fire

If prescribed fire is used as a follow-up treatment to stand thinning or as a standalone treatment, unacceptable levels of large diameter pine mortality may occur depending on management objectives. This mortality most often occurs as a direct result of cambium or crown injury to

individual trees during the fire. Mature ponderosa are susceptible to mortality during prescribed burns because of the deep duff and litter that has accumulated at their base in the absence of fire. These duff mounds typically burn at a slow rate, while maintaining lethal temperatures, causing severe cambium injury. To protect individual large diameter pine from lethal cambium injury, raking the duff away from the bases of these trees before burning (within 24" of the bole and down to mineral soil) is recommended.
White fir occurring in nearly pure stands tend to have very high levels of course woody debris on the forest floor as a result of downed logs from self-thinning, the continual shedding of branches and the remaining stems from old stands of brush that have been overtopped and killed by dense fir canopies. These types of stands produce tremendous amounts of heat on the ground surface and often cause severe injuries to the boles and crowns of standing trees, especially to smaller diameter trees. If high post-burn mortality levels in true fir stands, resulting in openings and possibly additional heavy fuel loading, is not an acceptable condition, than fuel treatments such as hand or tractor piling should be considered prior to or in place of prescribed fire. This is especially important in roadside units due to the potential for some fire-injured true fir to deteriorate into an unstable and hazardous condition.

Potential for funding through the Western Bark Beetle Program

Forest Health Protection may be able to assist with funding, including NEPA activities, for thinning within the Harvey project area. Thinning treatments that reduce stand density and change species compositions sufficient to lower the risk to bark beetle-caused mortality would meet the minimum requirements for Western Bark Beetle Program funding and would be supported by this evaluation. If you are interested in this competitive funding please contact me for assistance in developing and submitting a proposal.

If you have any questions regarding this report and/or need additional information please contact Danny Cluck at 530-252-6431.

/s/ Danny Cluck

Daniel R. Cluck
Forest Entomologist
NE CA Shared Service Area

cc: Lindsay Grayson, Forester, Eagle Lake RD
Rachel Rundquist, Forester, Eagle Lake RD
Forest Health Protection, Regional Office

References

Cochran, P.H., 1998. Examples of Mortality and Reduced Annual Increments of White Fir Induced by Drought, Insects, and Disease at Different Stand Densities. RNPNW-525. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 19 pp.

Egan, J.M., Jacobi, W.R., Negron, J.F., Smith, S.L., and Cluck, D.R. 2010. Forest thinning and subsequent bark beetle-caused mortality in Northeastern California. Forest Ecology and Management (260) 1832-1842.

Egan JM, Fournier D, Safford H, Sloughter JM, Cardoso T, Trainor P, Wenz J (2011) Assessment of a Jeffrey pine beetle outbreak from 1991–1996 near Spooner Junction, Lake Tahoe Basin. U.S. Department of Agriculture, Forest Service, Forest Health Protection, Sonora

Egan JM, Sloughter JM, Cardoso T, Trainor P, Wu K, Safford H, Fournier D. 2016. Multi-temporal ecological analysis of Jeffrey pine beetle outbreak dynamics within the Lake Tahoe Basin. The Society of Population Ecology.

Hood, S.M., Cluck, D.R., Jones, B.E., and Pinnell S. 2017. Radial and stand-level thinning treatments: 15-year growth response of legacy ponderosa and Jeffrey pine trees. *Restoration Ecology*. doi:10.1111/rec.12638

Long, J.N., and J.D. Shaw. 2005. A density management diagram for even-aged ponderosa pine stands. *West. J. Appl. For.* 20:205–215.

Long, J.N., and J.D. Shaw. 2012. A density management diagram for even-aged Sierra Nevada mixed-conifer stands. *West. J. Appl. For.* 27(4):187-195.
Oliver, W.W., 1995. Is self-thinning in ponderosa pine ruled by Dendroctonus bark beetles? In: Proceedings of the 1995 National Silviculture, Workshop, GTR-RM-267. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, C.O., pp., 213–218.

Oliver, W.W., 1995. Is self-thinning in ponderosa pine ruled by Dendroctonus bark beetles? In: Proceedings of the 1995 National Silviculture, Workshop, GTR-RM-267. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, C.O., pp., 213–218.

Schultz, D.E. 1994. Evaluation of White Fir Mortality on Big Valley RD (FPM Report NE94-2)

Insect and Disease Information

Jeffrey pine beetle

The Jeffrey pine beetle is the principle bark beetle found attacking Jeffrey pine, which is its only host. It is a native insect occurring from southwestern Oregon southward through California and western Nevada to northern Mexico. The beetle normally breeds in slow-growing, stressed trees. The beetles prefer trees which are large, mature, and occur singly rather than in groups. Yet when an epidemic occurs, the beetle may attack and kill groups of trees greater than 8 inches in diameter, regardless of age or vigor. Often the beetle infests lightning-struck or wind-thrown trees, but does not breed in slash.

Evidence of Attack
Presence of the beetle is usually detected when the foliage changes color. The color change of the foliage is related to the destruction of the cambium layer by the beetle. Generally, the top of the crown begins to fade in a slow sequence, with the needles turning from greenish yellow, to sorrel, and finally to reddish brown. By the time the tree is reddish brown, the beetles have usually abandoned the tree. Another sign of beetle attack is large, reddish pitch tubes projecting from the bark of the infested tree. If examined carefully, pitch tubes can be detected on infested green trees prior to crown fade. Jeffrey pine beetles have a distinctive "J" shape egg gallery pattern on the inner bark. Larval mines extend across the grain and end in open, oval-shaped pupal cells.

Life Stages and Development
The Jeffrey pine beetle is one of the larger pine bark beetles in California. The beetle has a 4 life stages, egg, larva, pupa, and adult. The adults are stout, cylindrical, black, and approximately five-sixteenths of an inch long when mature. The egg is oval and pearly-white. The larva is white, legless, and has a yellow head. The pupa is also white but is slightly smaller than the mature larva. The life cycle is normally completed in one year in the northern part of the range, but in the southern part, two generations per year may occur. The principle period of attack is in June and July, but attacks also are frequent in late September and early October. Similar to other *Dendroctonus* species, Jeffrey pine beetles use pheromones that attract other beetles to a tree, causing a mass attack that tends to overcome the tree's natural resistance. Blue stain fungi are associated with Jeffrey pine beetle attacks and aid in overcoming the tree’s defenses.

Conditions Affecting Outbreaks
Normally the Jeffrey pine beetle is kept in check by its natural enemies, climatic factors and the resistance of its host. Similar to other *Dendroctonus* species, the availability of suitable host material is a key factor influencing outbreaks. Healthy trees ordinarily produce abundant amounts of resin, which pitches out attacking beetles. When deprived of moisture, or stressed by other factors such as disease or fire injury, trees cannot produce sufficient resin flow and become susceptible to successful beetle attacks

Western Pine Beetle

The western pine beetle, *Dendroctonus brevicomis*, has been intensivly studied and has proven to be an important factor in the ecology and management of ponderosa pine thoughout the range of the host species (Miller and Keen 1960). This insect breeds in the main bole of living ponderosa pine larger than about 8 inches DBH. Normally it breeds in trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles emerge and attack trees continuously from spring through fall. Depending on the latidude and elevation, there can be from one to four generations per year.

Evidence of Attack

Initial attacks are made about mid-bole and subsequent attacks fill in above and below. Pitch tubes are formed on the tree trunk around the entry holes. Successful pitch tubes are red-brown masses of resin and boring dust. Relativly few, widely scattered white pitch tubes usually indicate that the attacks were not successful and that the tree should survive. Pheremones released during a successful attack attract other conspecifics. Attracted beetles may then spill over into nearby apparently healthy trees and overwhelm the tree with sheer numbers.

Life Stages and Development

These beetles pass thorugh the egg, larval, pupal and adult stages during a life cycle that varies in length dependent primarily on temperature. Adults bore a sinuous gallery pattern in the phloem and the female lays eggs in niches along the sides of the gallery. The larvae are small white grubs that first feed in the phloem then mine into the middle bark where they complete most of their development. Bluestain fungi inoculates the tree during successful attacks, blocking trachids and vessicles which contribute to the rapid tree mortality associated with bark beetle attacks.

Conditions affecting Outbreaks

Outbreaks of western pine beetle have been observed, and surveys made, in pine regions of the Westsince 1899 (Hopkins 1899; cited in Miller and Keen 1960). An insect survey completed in 1917 in northern California indicated that over 25 million board feet of pine timber had been killed by bark beetles.Information from surveys conducted in the 1930's indicated enormous losses attributed to the western pine beetle around that time. During the 1930's outbreak, most of the mortality occurred in stands of mature or overmature trees of poor vigor (Miller and Keen 1960). Group kills do not typically continue to increase in size though successive beetle generation as is typical with Mountain Pine Beetle and Jeffreay Pine Beetle. Rather, observations indicate that emerging beetles tend to leave the group kill area to initiate new attacks elsewhere.

The availability of suitable host material is a key condition influencing western pine beetle outbreaks. In northeastern California, drought stress may be the key condition influencing western pine beetle outbreaks. When healthy trees undergo a sudden and sever moisture stress populations of western pine beetle are likely to increase. Healthy trees ordinarily produce abundant resin, which pitch out attacking beetles, but when deprived of moisture, stressed trees cannot produce sufficient resin to resist the attack. Any condition that results in excessive demand for moisture, such as inter-tree completion, competing vegetation, or protracted drought periods; or any condition that reduces the ability of the roots to supply water to the tree, such as mechanical damage, root disease or soil compaction, can cause moisture stress and increase susceptibility to attack by the western pine beetle. Woodpeckers, predacious beetles, and low temperatures act as natural control agents when beetle populations are low (endemic populations).

Fir engraver beetle

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater than 4" in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack

Fir engravers bore entrance holes along the main stem, usually in areas that are > 4” in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the trees defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development
In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum,* into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year; however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks
Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Heterobasidion root disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores

produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentale* (also called the 'S' type) and *H. irregulare* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregulare* (‘P’ type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentale* (‘S’ type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentale* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

Dwarf mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic, flowering plants that can only survive on living conifers in the Pinaceae. They obtain most of their nutrients and all of their water and minerals from their hosts.

Dwarf mistletoes spread by means of seed. In the fall the fruit ripen and fall from the aerial shoots. The seeds are forcibly discharged. The seed is covered with a sticky substance and adheres to whatever it contacts. When a seed lands in a host tree crown, it usually sticks to a needle or twig, where it remains throughout the winter. The following spring the seed germinates and penetrates the twig at the base of the needle. For the next 2-4 years, the parasite grows within the host tissues, developing a root-like system within the inner bark and outer sapwood, and causing the twig or branch to swell. Aerial shoots then develop and bear seed in another 2-4 years.

Dispersal of dwarf mistletoe seeds is limited to the distance the seeds travel after being discharged. From overstory to understory, this is usually 20 to 60 feet, but wind may carry them as far as 100 feet from the source. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. There is some evidence that long distance spread of dwarf mistletoe is occassionaly vectored by birds and animals.

Vertical spread within tree crowns of most dwarf mistletoes is limited to less than one foot per year because of foliage density. Because of the thin crowns of gray pine, however, the vertical rate of spread has been measured as being greater than 2 feet per year. This rate of spread equalled or exceeded the rate of height growth of infected trees.

Dwarf mistletoes are easy to identify because they are generally exposed to view within a tree's crown. Signs of infection include the yellow-green to orange mistletoe plants, basal cups on a branch or stem where the plants were attached and detached plants on the ground beneath an infected tree. Symptoms include spindle-shaped branch swellings, witches' brooms in the lower crown, and bole swellings.